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In collaboration with the industrial sponsor:

Biomass and Fossil Fuel Research Alliance BF2RA
Outline

• Research Objectives
• Scenario for Simulation
• Simulation Development
• Analysis
• Future Work
Research Objectives

Working in conjunction with the sister project to develop:

• Fast processing simulation for biomass pellet milling
• Required output:
  – particle size distribution (PSD),
  – energy consumption,
  – mass throughput
• Aid decisions for biomass fuel choices by generators

Sister project PhD thesis by Dr. Orla Williams, “On Biomass Milling for Power Generation”, available online at http://eprints.nottingham.ac.uk/33464/
Scenario for Simulation:

**Mills and Mill Features**

- **Fuel and Air Inlet**
- **Fuel and Air Outlet**
- **Size Reduction** (Shearing/Abrasion induced by flailing hammers)
- **Classification via Perforated Screen**

**Hammer Mill Representation**

*Efficient Fossil Energy Technologies Engineering Doctorate (EngD) Centre*
Scenario for Simulation:

**Mills and Mill Features**

**Lupolco Ring and Roller Mill Representation**

- **Pressure loading rollers**
- **Classification**, By Dynamic Classifiers reject oversize particles
- By Elutriating Air unable to carry oversize particles
- **Size Reduction** (Compression/Abrasion induced by rollers and table)
- **Rotating Bed Table**
Simulation Development: Population Balance Equation

\[ \frac{df(x, t)}{dt} = \alpha(f_0(x)) - c(x)f(x, t) - s(x)f(x, t) + \int_x^\infty b(x, y)s(y)f(y, t)dy \]

- Conservation of properties (e.g. mass, volume, energy etc.)
- Governed by probabilistic functions, the selection and breakage functions, to determine the outcome
- Iterated to achieve steady-state operation
- Fast computational execution
Simulation Development: Selection and Breakage

The selection function determines the probability of a particle breaking based on certain conditions.

An analogy of this is if the trajectory of the ball is in a certain range, impact occurs, outside of this no impact occurs. We represent this as a probability, i.e. selected for breakage.

The breakage function determines what the particle breaks into given that it experiences an impact.

Larger initial particle sizes have a wider distribution of progeny particle sizes.
Simulation Development:
Energy Coupling Model

- Steady-state energy consumption determined quantity of size reduction in any time period
- Energy consumption is also subject to individual materials
- Model is dependent on the selection function and a material constant

\[ E_{t,j} = E_{\text{Mat}} \left( \frac{1}{x_j - x_i} \right), \]

where \( x_j > x_i \)

\( E_{\text{Mat}} \) : material constant
Experimental Data:

**Cutting Mill – Retsch SM300**

**Data Collected:**
- Milled sample for PSD analysis
  - Post experiment sieving and dynamic image analysis (Camsizer P4)
- Mass input/output flow rates:
  - Calculated from known mass and feeder timing
  - Data logging balance tracking
- Energy Consumption by mill
  - Elcomponent SPC Pro data logging

**Note:** Data from the sister project and supplemented with additional experiments are used to develop the model.
Simulation Analysis: Modelling Fitting and Analysis

- **Optimisation:** Constrained non-linear optimisation using an ‘interior-point’ algorithm

- **Overlapping co-efficient (OVL):** A measure for quantifying fit and objective function for optimisation based on the Probability Density Function of the PSD

\[
OVL = \int_0^\infty \min\{Actual, Simulated\} \, dx
\]
Simulation Analysis:
Modelling Fitting

Model is trained to a minimum OVL = 0.86 with a preferential selection and breakage functions:

\[ s_i = \left( \frac{X_i}{X_0} \right)^\alpha \quad \& \quad b_{i,j} = 1 - e^{-\left( \frac{X_i}{X_j} \right)^\beta} \]

| \( x_i \) | - Initial particle size |
| \( x_j \) | - Particle of size >\( x_i \) |
| \( x_0 \) | - Largest particle size |
| \( \alpha, \beta, \gamma \) | - Fitted Parameter Values |
Simulation Analysis: Parameter Variation I

Effect of Mill Speed on Parameter $\alpha$

Combination of higher feed rate with smaller screen is highly influential at low speeds.

At high speeds, all other parameters become negligible.

Graph showing the effect of mill speed on parameter $\alpha$ with different feed rates and screen sizes.
Simulation Analysis: Parameter Variation II

Effect of Feed Rate on Parameter $\alpha$

Effect of Feed Rate on Parameter Alpha

At high speeds, effects of feed rate become negligible

1.5 mm screen

4 mm screen

Parameters:
- 1100-1.5
- 1100-4
- 1900-1.5
- 1900-4
- 3000-4
- 3000-1.5

Graph shows the parameter value varying with feed rate.
Simulation Analysis:

Key Summary Conclusions

- Model is optimising parameters in a manner that reflects mill operation such as:
  - Smaller mill screen size results in narrower spread of particle sizes
  - Feed rate has a greater effect when screen size is small
  - As mill speed increases, influence from other variables diminishes

- Complex yet distinctive relationships identified in the analysis of optimised parameters

- Most influential milling variable on the parameters is screen aperture when mill speeds are low

- Milling energy requires a more quantitative correlation with pellet characteristics
Future Work:

Material Characterisation

**Objective:**

Establish a relationship between pellet characteristics and its potential for grinding with energy required to achieve its comminution.

**Challenges:**

- Pellet making processes vary
- Use of binders varies

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**Computerised Tomography**

- Identification of Void Space Volume
- Identification of Crack Lengths
Future Work:

Material Characterisation

**Compressive/Shear Strength Testing**

Testing to a correlation between CT results for void space and crack lengths with compressive and shear strength results

**Note:** As part of the sister project experiments of this type were completed however never correlated to other specific characteristics of the pellet, which is the aim of this line of investigation.
Future Work:

Lupolco Ring and Roller Mill

Objective: test performance of the model on a different style mill

Further Still: Hand off for industrial partners implementation and assessment
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Thank you

If you have any questions please feel free to contact me:

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Key References


